Geologic Map of the Upper Hurricane Wash and Vicinity, Mohave County, Northwestern Arizona

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Prepared in cooperation with the
National Park Service and the
Bureau of Land Management

Pamphlet to accompany
Miscellaneous Field Studies Map MF-2410

2003

U.S. Department of the Interior
U.S. Geological Survey

INTRODUCTION

Hurricane Wash is the principal drainage for the Upper Hurricane Valley just west of and parallel to the Hurricane Cliffs, northern Mohave County, Arizona. Hurricane Wash begins near the abandoned village of Mt. Trumbull (Bundyville), Arizona, about 8 km (5 mi) south of the map area. The nearest settlements are St. George, Utah, about 30 km (19 mi) north of the map area, and Colorado City, Arizona, about 30 km (20 mi) northeast of the map area (Fig. 1). Altitudes range from about 1,250 m (4,100 ft) at Hurricane Wash (northeast corner of the map) to 1,967 m (6,452 ft) at the Hurricane Cliffs (southeast corner of the map). Access to the map area is by improved dirt roads locally referred to as the Mt. Trumbull Road from St. George, Utah, and the Navajo Trail from Colorado City, Arizona (Fig. 1). The Mount Dellenbaugh road and several unimproved dirt roads lead from the Mt. Trumbull Road and Navajo Trail to various locations within the map area.

The U.S. Bureau of Land Management, Arizona Strip Field Office, St. George, Utah, manages the area including about 17.5 sections belonging to the State of Arizona and about 5.5 sections of private land in the vicinity of Hurricane Wash, southeast corner of the map area (U.S. Department of the Interior, 1993). At elevations below about 1,500 m (5,000 ft), the area supports a moderate to thick growth of sagebrush, cactus, cliffrose bush, grass, and various high-desert shrubs. At higher elevations, thick to moderate growths of sagebrush thrive in alluvial valleys and a moderate cover of pinyon pine and juniper trees is common east of the Hurricane Cliffs.

PREVIOUS WORK

The area was mapped photogeologically by Wilson and others (1969) and later modified by Reynolds (1988). Four preliminary geologic maps were made by Billingsley (1993b, c, d, e) of the map area at a scale of 1:24,000 (Fig. 1). A geologic map has been completed for the lower Hurricane Wash and vicinity (Billingsley and Graham, in press), which borders the north edge of the map; the Wolf Hole Mountain and vicinity map (Billingsley, 1993a) lies adjacent to the northwest corner of this map; the Sullivan Draw and vicinity map (Billingsley, 1994) borders the west edge; the Hidden Hills and vicinity map (Billingsley and others, 2002b) lies adjacent to the southwest corner; the upper Parashant Canyon and vicinity map (Billingsley and others, 2000) borders the south edge; the Uinkaret Volcanic Field and vicinity map (Billingsley and others, 2001) is adjacent to the southeast corner of the map; the Clayhole Valley and vicinity map (Billingsley and Priest, 2003) borders the east edge; and the Clayhole Wash and vicinity map (Billingsley and others, 2002a) lies adjacent to the northeast corner of the map area (Fig. 1). Geologic maps are also available for the Grand Canyon area about 30 km (18 mi) south of the map area by Huntoon and others (1981) and Wenrich and others (1996).

MAPPING METHODS

Photogeologic mapping at the 1:24,000-scale began in early 1992 and ended in late 1993. In particular, many of the Quaternary alluvial units having similar lithologies were mapped on the basis of geomorphic features observed on aerial photographs. Field investigations were then conducted to assure accuracy and consistency of all map units and structures.

GEOLOGIC SETTING

The map area lies within the Shivwits and Uinkaret Plateaus, subplateaus of the southwest part of the Colorado Plateau physiographic province. The physiographic boundary between the higher elevation of the Uinkaret Plateau and the lower Shivwits Plateau is the upper part of the Hurricane Cliffs fault scarp (cross section A-A'). Relatively flat-lying Paleozoic and Mesozoic strata that have an average regional dip toward the east of less than 2º characterize the Shivwits and Uinkaret Plateaus.

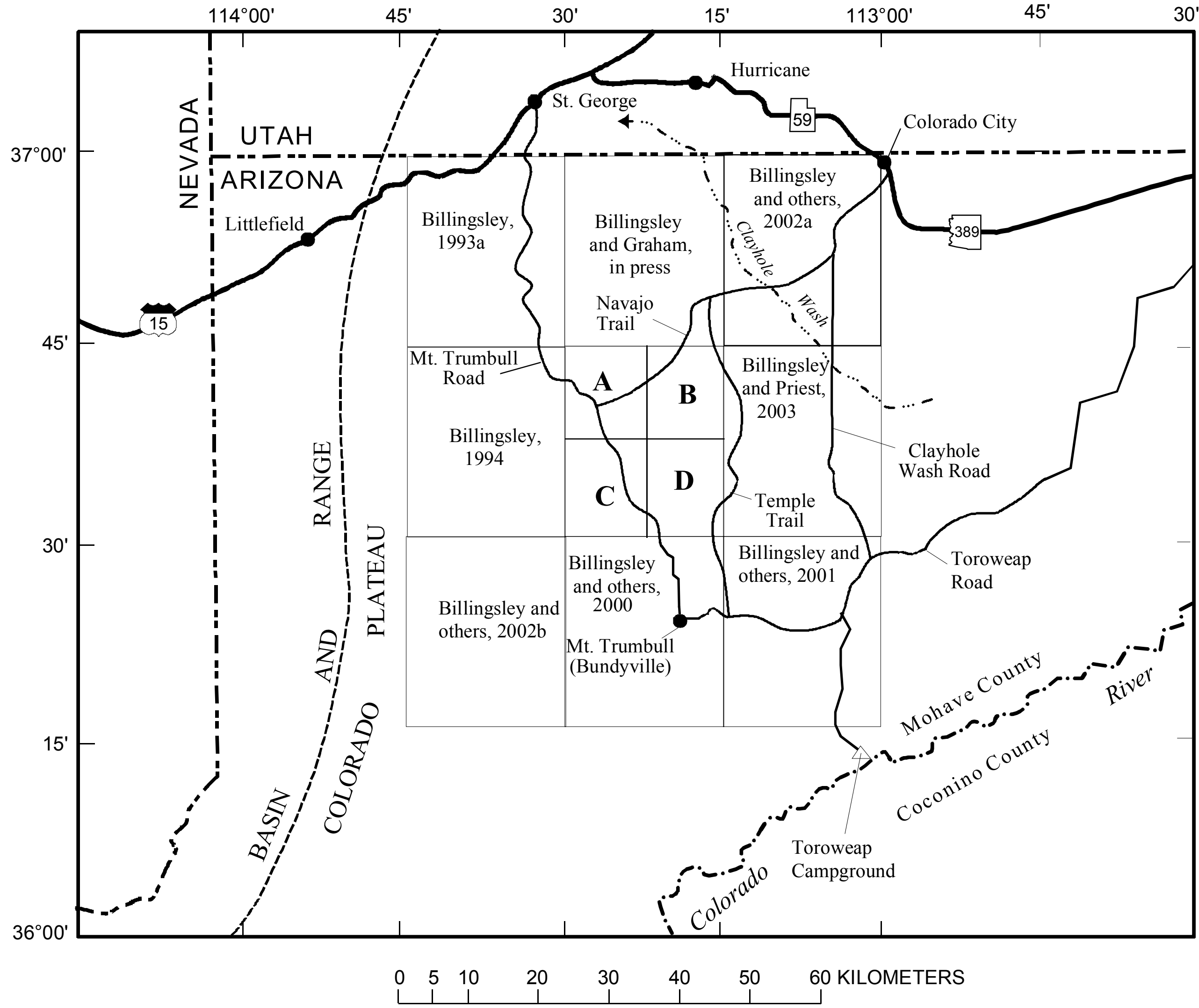

Figure 1. Map showing the Dutchman Draw (A), The Grandstand (B), Little Tanks (C), and Russell Spring (D), U.S. Geological Survey 7.5' quadrangles and adjacent mapped areas, northern Mohave County, northwest Arizona.

The Hurricane Fault and Monocline are the major structural features of the map area. The resulting fault scarp, the Hurricane Cliffs, exposes more than 365 m (1,200 ft) of Permian strata. West of the Hurricane Cliffs, about 280 m (920 ft) of Triassic strata are exposed under the Tertiary basalt flows of Diamond Butte and Twin Butte. Vertical displacement among various segments of the Hurricane Fault are estimated to be at least 510 m (1,675 ft) just north of the map area, and as much as 670 m (2,200 ft) in the southeast part. Several graben and horst structures and the Main Street Fault have a strike parallel to the Hurricane Fault in the north half of the map area. These graben and horst structures reflect a southwest-northeast extensional regime during late Quaternary time (Huntoon, 1989).

Cenozoic deposits are widely distributed in the map area consisting of Quaternary and Tertiary volcanic rocks, Quaternary surficial alluvium, and landslide debris. The volcanic rocks mapped are dikes, pyroclastic deposits, and basalt flows. Man-made earthen dams, drainage ditches, and quarries are also mapped. Map contacts between most Quaternary deposits are arbitrary because of intertonguing and (or) gradational lateral and vertical changes. Surficial deposits include artificial fill and quarries, stream-terraces, alluvial fans, talus, and landslide debris. The surficial deposits are identified by photogeologic techniques based on their geomorphic relations to structural features and erosional surfaces. These deposits form geomorphic landforms with intertonguing and gradational contacts. The subdivision of Quaternary deposits are intentionally detailed because these units strongly influence the management of rangeland, flood control, biological studies, soil erosion, and the planning of road construction by federal, state and private organizations.

STRATIGRAPHY

The Paleozoic and Mesozoic units within the map area include, in order of decreasing age, the Hermit, Toroweap, and Kaibab Formations (Lower Permian), and the Moenkopi Formation (Lower and Middle? Triassic). Only a few hundred meters of the upper part of the Hermit Formation is exposed along the base of the Hurricane Cliffs. The Coconino Sandstone found in the Grand Canyon area about 32 km (20 mi) south of the map area pinches out northward and does not reach the map area except as a thin discontinuous crossbedded sandstone lense within the lower part of the Seligman Member of the Toroweap Formation (Billingsley and others, 2000; 2001). The Toroweap Formation is well exposed in the lower steep slopes and cliffs of the Hurricane Cliffs as a gray siltstone, sandstone, gypsum, and limestone. About three-fourths of the exposed bedrock surface of the Shivwits and Uinkaret Plateaus is composed of gray cherty limestone and gray to white siltstone and gypsum of the Kaibab Formation. The Kaibab Formation forms the upper part of the Hurricane Cliffs. About one-quarter of the plateau surface bedrock is gray conglomerate and sandstone, red siltstone and sandstone, and gray gypsum and dolomite of the Moenkopi Formation. Most of the Moenkopi Formation crops out along the base of the Hurricane Cliffs and is largely covered by surficial alluvial deposits.

The basalt flow capping Diamond Butte is probably the same basalt capping Twin Butte, 4 km (2.5 mi) east of Diamond Butte because they overlie similar strata of the Moenkopi Formation, are stratigraphically at similar elevations, and are composed of alkali-olivine basalt (Hamblin, 1970; Billingsley 1993d, e). Therefore, the basalt flow on Diamond Butte and Twin Butte (southeast part of map area), are informally named the basalt of Diamond Butte for Diamond Butte, the type area, northern Mohave County, Arizona (sec. 33, T. 37 N., R. 10 W.). The basalt of Diamond Butte is comprised of one or more olivine basalt flows that lack associated dikes or pyroclastic material. A sample of the basalt collected on the east side of Diamond Butte (central part of sec. 34, T. 37 N., R. 10 W.), yielded a K-Ar age of 4.3±0.6 Ma (Harold Mehnert, U.S. Geological Survey, written commun., 1993).

The basalt of Diamond Butte overlies a Tertiary erosion surface of the lower part the upper red member of the Moenkopi Formation at Diamond Butte and the upper part of the upper red member of the Moenkopi Formation at Twin Butte. Thus, the Hurricane Monocline folded the Triassic rocks, which were later beveled by erosion prior to the deposition of the basalt of Diamond Butte. The basalt of Diamond Butte flowed in an easterly direction from an unknown source in the Diamond Butte area down a gently eroded bedrock surface of red sandstone and siltstone of the upper red member of the Moenkopi Formation across the Hurricane Monocline. Feeder dikes for the basalt flows on Diamond Butte could be present under landslide debris that surrounds the Diamond Butte area. The eastward flow of the basalt of Diamond Butte appears to have terminated just short of the Hurricane Fault, perhaps along a north-south strike valley of the Hurricane Monocline because the basalt is not found east of the fault. If part of the basalt extended east across the Hurricane Fault, all traces of the basalt east of the fault have been eroded away along with most of the Moenkopi Formation and upper part of the Kaibab Formation. The Hurricane Fault would have displaced the basalt of Diamond Butte within the past 4.3 m.y. if it had extended east of the fault because the fault offsets the basalt of Bundyville, a similar age basalt about 19 km (12 mi) south of Diamond Butte (Koons, 1945; Billingsley and others, 2000). The basalt of Bundyville (3.6 Ma; Reynolds and others, 1986) is offset equally as much as the underlying strata indicating that displacement along this section of the Hurricane Fault occurred within the past 3.6 m.y.

The basalt of Diamond Butte is stratigraphically at a similar position as other Tertiary basalts on the Uinkaret and Shivwits Plateaus. The 3.47±0.6-Ma Mount Trumbull basalt of Hamblin and Best (1970) is 11 km (7 mi) southeast of the map area, and the 3.6±0.18-Ma basalt of Bundyville along the Hurricane Cliffs is 19 km (12 mi) south of Diamond Butte (Reynolds and others, 1986). Another isolated outcrop of basalt at a similar stratigraphic position as the basalt of Diamond Butte is at the basalt of Poverty Knoll about 11 km (7 mi) southwest of Diamond Butte. The age of the basalt flow on Poverty Knoll is not known, but farther southwest at Poverty Mountain, the K-Ar age for another lithologically and stratigraphically similar basalt is 4.75±0.26 Ma (Reynolds and others, 1986).

At the extreme east-central edge of the map area, a basalt flow is cut by three segments of the Hurricane Fault. This basalt flow came from a pyroclastic volcano called Moriah Knoll about 6.4 km (4 mi) southeast of the map area. This alkali-olivine basalt flow is informally named the basalt of Moriah Knoll for Moriah Knoll (secs. 12 and 13, T. 37 N., Rs. 8 and 9 W.; Billingsley and Priest, 2003; and Billingsley and Workman, 2000). The basalt of Moriah Knoll is considered to be Pleistocene in age because of its relation to the Basalt of Antelope Knoll (830 ka) near Clayhole Wash 6 km (3.75 mi) east of the map area. A sample from the basalt at the base of the Hurricane Cliffs yielded a K-Ar age of 2.3±1.5 Ma, and a sample near Moriah Knoll yielded a K-Ar age of 1.5±1.5 Ma. These ages, however, are not reliable because of too much alteration and contamination of the sample (Harold Mehnert, U.S. Geological Survey, written commun., 1993). For now, the basalt of Moriah Knoll is about 830 ka.

The basalt of Moriah Knoll fills a shallow minor north-trending drainage east of the Hurricane Fault eroded into the soft gypsum and siltstone of the Harrisburg Member of the Kaibab Formation, Uinkaret Plateau. The drainage continues over the Hurricane Cliffs and down onto outcrops of the Harrisburg Member of the Kaibab Formation and alluvial slopes of the Shivwits Plateau below. The drainage that the basalt of Moriah Knoll occupies had deepened by headward erosion for a short distance into the Hurricane Cliffs fault prior to deposition of the basalt. The basalt still clings to steep canyon walls of the Fossil Mountain Member of the Kaibab Formation where the flow had descended about 80 m (265 ft) to the first down-dropped, east-dipping fault block of Kaibab strata on the west side of the Hurricane Fault. There are three segments of the Hurricane Fault that the basalt of Moriah Knoll flowed across. Members of the Kaibab Formation west of the Hurricane Fault dip east as much as 24° toward the fault scarp. Displacement along the first segment of the Hurricane Fault before the basalt flow was about 110 m (360 ft). After crossing the first segment of the Hurricane Fault, the basalt of Moriah Knoll divided into two flows; one flowed south a short distance along the base of the first segment of the Hurricane Fault scarp, and the bulk of the flow continued northwest and steeply down and across the second segment of the Hurricane Fault. The basalt flowed over thin alluvial deposits and the beveled east-dipping strata of the Harrisburg and Fossil Mountain Members of the Kaibab Formation as it continued northwest down a steep drainage onto the Shivwits Plateau.

Sometime after the basalt of Moriah Knoll cooled, the basalt became offset down-to-the-west along all three segments of the Hurricane Fault; about 73 m (240 ft) along the main or first segment, about 26 m (85 ft) along the second segment, and about 30 m (100 ft) along the third and westernmost segment for a total of about 124 m (407 ft) or more in the past 850,000 years. Minimum vertical offset along the various segments of the Hurricane Fault at this location before the eruption of the basalt of Moriah Knoll is estimated to be as much as 380 m (1,250 ft). Total estimated offset along the Hurricane Fault segments is estimated at over 510 m (1,675 ft).

About 1.5 km (1 mi) south of Diamond Butte, there is a volcanic complex of flows and associated dikes and pyroclastic deposits (Billingsley, 1993d). These volcanic deposits were named by Billingsley and Workman (2000), and the Little Tanks Basalt was named for Little Tanks, the type area, northern Mohave County, Arizona (sec. 5, T. 36 N., R. 10 W.). The Little Tanks Basalt is just east and southeast of Little Tanks, a large and important stock pond of domestic water for the area. The Little Tanks Basalt overlies Cenozoic alluvial deposits, bedrock strata of the Harrisburg Member of the Kaibab Formation and bedrock of the lower red member and Virgin Limestone Member of the Moenkopi Formation. The Little Tanks Basalt is approximately 335 m (1,100 ft) stratigraphically below the basalt of Diamond Butte. A sample obtained from the Little Tanks Basalt yielded a K-Ar age of 1.0±0.4 Ma (Harold Mehnert, U.S. Geological Survey, written commun., 1993).

Denudation of Triassic sedimentary rocks during the past 3.3 m.y. between the deposition of the basalt of Diamond Butte and intrusion of the Little Tanks Basalt removed approximately 335 m (1,100 ft) of Triassic rocks, a denudation rate of about 101 m/m.y. (330 ft/m.y.), or 1 m (3 ft/10,000 yr). The Little Tanks Basalt overlies flat alluvial plains and bedrock just west of Hurricane Wash. Hurricane Wash is presently about 40 m (130 ft) lower than the 1-Ma Little Tanks Basalt suggesting a rate of downcutting for Hurricane Wash in the past million years at about 0.4 m (1.3 ft/10,000 yr).

The predominantly Quaternary age assigned to the alluvial deposits in the map area is based mainly on field relation of these deposits to the Pliocene and Pleistocene basalts of this map area and other adjoining geologic maps (Billingsley, 1993a; Billingsley and others, 2000, 2001, 2002a, b). Many alluvial deposits contain basalt clasts that are downslope from basaltic outcrops of Pliocene and Pleistocene age. Allowing time for erosion and deposition as calculated above, all alluvial and surficial deposits of this map area are probably Pleistocene and Holocene age.

STRUCTURAL GEOLOGY

Structural features in the map area show up particularly well on X-Band, side-looking radar (SAR) images of the U.S. Geological Survey 1:250,000-scale Grand Canyon quadrangle, Arizona. These images give an overall perspective of the structural fabric of this part of Arizona, especially in flatland areas (Western Atlas International, Inc., 1988).

There are two major faults in the map area, the Hurricane and Main Street Faults. The Hurricane and Main Street Faults strike northwest in the north half of the map and southwest in the central part of the map. However, the strike of the Hurricane Fault turns southwest in the central part of the map and then south in the south part. The axis of the Hurricane Monocline is located approximately just west of and parallel to the Hurricane Fault because the greatest bend of strata is found on the downthrown block where strata dip as much as 24° in the northeast part of the map, and as much as 12° in the south part. These steep dips do not reflect the initial dip of the Hurricane Monocline, but are the results of reverse drag on the downthrown side of the Hurricane Fault that accentuates the dip (Hamblin, 1965).

The axis of the Hurricane Monocline is approximately just east of the Hurricane Fault based on deep exposures in the Grand Canyon about 40 km (25 mi) south of the map area (Huntoon, 1989; Huntoon and others, 1981; Wenrich and others, 1996). Strata east of the Hurricane Fault dip east from 2° to 4°. Changes in strike of exposed monoclines in the eastern Grand Canyon area are linked to intersecting basement faults that have been reactivated during the late Cenozoic (Huntoon, 1989). Because alluvial deposits cover the strata along the northeast segment of the Hurricane Monocline in the east central part of the map area, dip of the strata is unknown.

The Hurricane Fault scarp forms the Hurricane Cliffs, a prominent landmark in this area of Arizona known regionally as the Arizona Strip. The estimated displacement of strata along the Hurricane Fault in the northeast part of the map is about 510 m (1,675 ft) down-to-the-west, increasing to about 670 m (2,200 ft) in the southeast part. Strata are generally east dipping on both sides of the fault partly reflecting the monoclinal flexure. The Hurricane Fault is mostly covered by talus and alluvial deposits but appears to be a normal vertical fault as suggested by Hamblin and Best (1970). The Hurricane Fault cuts alluvial deposits as much as 25 m (82 ft) along various segments of the fault. Even though the fault line is clearly located in alluvial deposits, the fault is dotted on the map because of extensive talus and alluvial cover.

The graben and horst structures found on the downthrown side of the Hurricane Monocline are partly buried under thick alluvial deposits in the map area. Tertiary compressional stresses resulted in the development of the Hurricane Monocline along favorably oriented, pre-existing faults in the Precambrian basement in Laramide time (Huntoon, 1989; Elston and Young, 1991). The resulting compression produced easterly dips of as much as 5° or more in strata along the Hurricane Monocline. The dip of fault planes are not exposed in the map area, but in Grand Canyon, the dips of all fault planes are within 5° of vertical toward the west.

By late Oligocene time, the west part of the Colorado Plateau was probably undergoing the first significant shallow east-west crustal extension to affect the region since late Precambrian time (Rowley and others, 1978). However, this extension does not appear to have affected the Hurricane Monocline until latest Pliocene and early Pleistocene time. The extension along deep-seated fault planes allowed normal vertical faults to cut all Paleozoic and Mesozoic strata but reversed the displacement of strata down-to-the-west and accentuated the eastward dip of strata along the downthrown blocks of the Hurricane Fault (Huntoon, 1989). Southwest-northeast or east-west extension is currently in progress as indicated by faulted alluvium and a recent earthquake in September 1992 (Billingsley, 1993a; Billingsley and Graham, in press).

The equal offset of the 3.6±0.18-Ma basalt of Bundyville and underlying Mesozoic strata along the Hurricane Fault 13 km (8 mi) south of the map area indicate that displacement of the Hurricane Fault and associated graben structures are the result of Pliocene-Pleistocene east-west extension that caused down-to-the-west, near vertical normal faulting that formed the Hurricane Cliffs in the last 3.6 m.y. As previously discussed, the basalt of Bundyville and the basalt of Moriah Knoll brackets approximately 380 m (1,245 ft) of vertical displacement along the Hurricane Fault between 3.6 Ma and 850 ka with an additional 130 m (430 ft) of displacement within the past 850 thousand years. Just north of the Arizona-Utah State line near the town of Hurricane, Utah, a basalt flow dated at 0.293±0.087 Ma is vertically displaced 87 m (285 ft) by the Hurricane Fault (Hamblin and others, 1981).

Holocene movements have occurred along parts of the Hurricane Fault and many other faults in the map area as demonstrated by fault scarps in talus and alluvial deposits that are easily defined in the field and on aerial photographs. However, erosion by Holocene mass wasting and solution of gypsum within the Kaibab Formation has shed loose debris over unconsolidated alluvial scarps. Thus, several faults are shown on the map as dotted lines in alluvial units but often form map-unit contacts. Where fault scarps appear fresh in Holocene alluvial material, they are shown as solid lines. The faults shown as solid lines in alluvial deposits suggest that recent displacements are restricted to short segments along various faults, usually less than a 2-km-long (1-mi-long) distance. All of the faults in the map area began to develop after deposition of Pliocene basalt flows starting as early as 3 Ma.

Significant but less regionally extensive structures west of the Hurricane Fault include the Main Street Graben and Horst (Billingsley, 1992, 1993a, b). The Main Street Graben and Horst, and several lesser parallel grabens and horsts all have a northwest strike in the north half of the map area. At the northwest corner of the map area, the Main Street Graben averages about 1 km (0.5 mi) wide and the Main Street Horst is about 2 km (1.25 mi) wide. The Main Street Horst widens to more than 7 km (4.5 mi) where it dies out in the central part of the map area. Main Street Fault forms the east-bounding fault of Main Street Graben and the west-bounding fault of Main Street Horst. The Sunshine Fault forms the east-bounding fault of Main Street Horst.

The nearly vertical Main Street Fault, first described by Hamblin and Best (1970), displaces strata down-to-the-west-southwest about 122 m (400 ft) at the northwest corner of the map, and down to the northwest about 60 m (200 ft) in the southwest part of the map area. Bedrock strata on either side of the Main Street Fault dip gently east and northeast in the northwest quarter of the map and east to southeast in the southwest part. In the central part of the map, a 3-km- (2 mi)-long segment of the Main Street Fault near Diamond Butte is buried by alluvial deposits. The SAR image strongly suggests that the Main Street Fault is continuous near Diamond Butte and that it changes strike from northwest to southwest; its location on the map is approximate.

The bend in strike of the Main Street Fault coincides with a similar bend in strike of the Hurricane Fault. In fact, all northwest striking grabens, horsts, and folds in the north half of the map terminate southward along a northeast trend that aligns with the southwest bend in strike of the Hurricane and Main Street Faults. This northeast trend may reflect a deep-seated northeast-trending structure of Precambrian age, which may have caused the dramatic change in strike for all structures.

About 12 km (7.5 mi) north of the map area, the Main Street Fault equally displaces the Seegmiller Mountain Basalt and the Moenkopi Formation down-to-the-west. Thus, the fault is younger than the Seegmiller Mountain Basalt, which is about 2.4 Ma in age (Billingsley, 1992, 1993a). Pleistocene basalts as young as 1.4 Ma in age and the underlying strata are equally offset by normal vertical faults north and northwest of the map area (Billingsley and Graham, in press). Thus, on the basis of geological mapping of this region it is likely that all faults in the map area, with the exception of the Hurricane Fault, developed during or since the early Pleistocene.

A small dome structure near the center of the map is thought to be the result of a volcanic intrusion. Small folds in the map area are probably related, in part, to early Laramide compressional stresses (Huntoon, 1989). Later extension stresses allowed strata to bend or fold into graben structures. Locally, warped and bent strata, too small to show at map scale, are the result of dissolution of gypsum within the Harrisburg Member of the Kaibab Formation and are commonly associated with the dissolution of gypsum along drainages.

Circular collapse structures that have inward-dipping strata may be collapse-formed breccia pipes that originated in the deeply buried Mississippian Redwall Limestone (Wenrich and Huntoon, 1989; Wenrich and Sutphin, 1989). Such features are marked on the map by a dot and the letter C. However, they cannot be distinguished with certainty from shallow collapse structures caused by the dissolution of gypsum in the Toroweap or Kaibab Formations. Moreover, some of the deep-seated breccia pipes are overlain by gypsum collapse features (Wenrich and others, 1996). The deep-seated breccia pipes potentially contain economic deposits of copper and uranium minerals (Wenrich, 1985).

An abandoned copper prospect is about 3 km (2 mi) east of Main Street Valley, northwest-central part of the map, and does not appear to be associated with a collapse structure or any other structures (NW¼ sec. 31, T. 38 N., R. 10 W.). The prospect consists of a small 2-m (6 ft)-deep shaft and nearby minor bulldozer scrapings. Copper production from this prospect was minor, if any at all. Copper minerals present are azurite and malachite in a sandy limestone bed of the middle cliff unit of the Harrisburg Member of the Kaibab Formation. The copper deposits here are very similar to the strataform copper deposits on the Kaibab Plateau near Jacobs Lake, Arizona, about 107 km (67 mi) east of this prospect (Billingsley and others, 1997).

The shallow sinkholes and caves on the plateau surfaces are associated with the dissolution of gypsum in the Harrisburg Member of the Kaibab Formation. The sinkholes are relatively young features of Holocene and probable Pleistocene age because of their young appearance. Hundreds of sinkhole depressions that are breached by drainages on the Shivwits and Uinkaret Plateaus surfaces are not marked on this map. Only the sinkholes that form an enclosed basin or depression are shown by a triangle symbol. Several minor drainages originate or terminate at breached sinkhole depressions in the map area.

ACKNOWLEDGMENTS

We appreciate the advice, revisions, and information for this report by the following individuals: Jonathan C. Matti, David S. Harwood, Wendell Duffield, Thomas W. Judkins, Susan Priest, and Angela Jayko of the U.S. Geological Survey. I am grateful to Roger Carroll, Beatrice Landavazo, Hugh Thomas, and Theresa Iki of the U.S. Geological Survey for their technical assistance in producing this map. Aerial photos provided by Becky Hammond, geologist with the Bureau of Land Management, Arizona Strip Field Office, St. George, Utah are greatly appreciated.

DESCRIPTION OF MAP UNITS

SURFICIAL DEPOSITS

Surficial deposits (Holocene and Pleistocene)—Surficial deposits are differentiated from one another chiefly on the basis of difference in morphologic character and physiographic position observed on aerial photographs. Older alluvial fans and terrace-gravel deposits generally exhibit extensive erosion, whereas younger deposits are actively accumulating material or are lightly eroded as observed on 1976 aerial photographs

Qaf **Artificial fill deposits and quarries (Holocene)**—Alluvial and bedrock material removed from pits and trenches to build stock tanks and drainage diversion dams

Qs **Stream-channel alluvium (Holocene)**—Unconsolidated and poorly sorted, interbedded silt, sand, and pebble to boulder gravel. Found in active wash or large arroyos. Intertongue, inset to, or locally overlie floodplain (Qf), valley-fill (Qv), young, intermediate and old alluvial fan (Qa_1, Qa_2, Qa_3), and young and intermediate terrace-gravel (Qg_1, Qg_2) deposits. Stream channels subject to high-energy flows and flash floods and support little or no vegetation. Thickness, 1 to 3 m (3 to 10 ft)

Qf **Flood plain deposits (Holocene)**—Unconsolidated, light-gray or brown silt, sand, and lenses of pebble to cobble gravel. Locally partly cemented by clay, calcite, and gypsum. Deposit intertongues, merges, inset against, or locally overlie valley-fill (Qv), and young and intermediate alluvial fan (Qa_1 and Qa_2) deposits. Form wide flat valley floors as opposed to narrow concave valley profiles of valley-fill (Qv) deposits. Locally cut by arroyos. Subject to frequent flooding and local temporary ponding. Sparsely vegetated by grass. Thickness, 25 m (80 ft) or more

Qg_1 **Young terrace-gravel deposits (Holocene)**—Unconsolidated, light-brown to pale-red siltstone, sandstone, and lenses of gravel containing pebbles and boulders of well-rounded limestone and sandstone and angular and subrounded chert derived from Kaibab and Toroweap Formations. Include lenses of gray silt and sand and locally include well-rounded to subangular basalt clasts along Hurricane Wash. Include reworked materials from young, intermediate and old alluvial fan (Qa_1, Qa_2, Qa_3), intermediate and old terrace-gravel (Qg_2, Qg_3), talus (Qt), and landslide (Ql) deposits. Locally cut by arroyos as deep as 4 m (13 ft) along Hurricane Wash. Form alluvial benches about 1 to 4 m (3 to 13 ft) above local streambeds. Thickness, 1 to 6 m (3 to 20 ft)

Qa_1 **Young alluvial fan deposits (Holocene)**—Unconsolidated, gray silt and sand. Contain lenses of coarse gravel composed of subangular to rounded pebbles and cobbles of limestone, chert, and sandstone locally derived from Hermit, Toroweap, Kaibab, and Moenkopi Formations. Locally include well-rounded to subangular basalt clasts from basalt flows of Diamond Butte and Twin Butte and from Little Tanks Basalt near Hurricane Wash, southwest corner of map area. Partly cemented by gypsum and calcite. Overlap, intertongue, or partly include reworked materials from stream-channel alluvium (Qs), valley-fill (Qv), and young, intermediate, and old terrace-gravel (Qg_1, Qg_2, Qg_3) deposits, and intermediate and old alluvial fan (Qa_2, Qa_3) deposits near their downslope ends. Alluvial fan deposits subject to erosion by sheetwash erosion and flash floods. Support sparse growths of sagebrush, cactus, and grass. Thickness, 6 m (20 ft)

Qv **Valley-fill deposits (Holocene and Pleistocene)**—Partly consolidated, gray and light-brown silt, sand, and lenses of pebble to small-boulder gravel. Intertongue or overlap talus (Qt), flood plain (Qf), young terrace-gravel (Qg_1), and young, intermediate and old alluvial fan (Qa_1, Qa_2, Qa_3) deposits. Subject to sheetwash flooding and temporary ponding; cut by arroyos as much as 2 m (6 ft) deep in larger valleys. Support moderate growths of sagebrush, grass, and cactus. Form concave-shaped valley cross-sectional profiles as opposed to flat-valley floors of flood plain (Qf) deposits. Thickness, 6 m (20 ft)

Qt **Talus deposits (Holocene and Pleistocene)**—Unsorted debris consisting of breccia composed of small and large angular blocks of local bedrock as much as 1 m in diameter. Include silt, sand, and gravel; partly cemented by calcite and gypsum. Intertongue with young, intermediate, and old alluvial fan (Qa_1, Qa_2, Qa_3), valley-fill (Qv), young, and intermediate terrace-gravel (Qg_1, Qg_2) deposits. Support sparse to moderate growths of sagebrush, cactus, and grass. Only relatively extensive deposits shown. Thickness, 3 m (10 ft)

Ql **Landslide deposits (Holocene and Pleistocene)**—Unconsolidated and unsorted masses of rock debris, including detached blocks of bedrock strata that have rotated backward and slid downslope as loose incoherent masses of broken rock and deformed strata, often surrounded by talus (Qt) deposits. Found principally below basalt flows at Diamond Butte and Twin Butte. Include limestone bedrock strata of Fossil Mountain Member of the Kaibab Formation along upper part of the Hurricane Cliffs. Support sparse growths of sagebrush, cactus, grass, juniper and pinyon pine trees. May become unstable in wet climatic conditions. Only large masses are shown. Thickness, 35 to 45 m (115 to 150 ft)

Qg_2 **Intermediate terrace-gravel deposits (Holocene and Pleistocene)**—Similar to young terrace-gravel deposits (Qg_1) but partly consolidated. Contain well-rounded basalt clasts as much as 5 cm (2 in) or more in diameter. Form flat benches as abandoned stream channels about 2 to 4 m (6 to 15 ft) above local streambeds and about 1 to 2 m (3 to 6 ft) above young-terrace gravel (Qg_1), and flood plain (Qf) deposits. Interbedded and locally overlain by talus (Qt) and young alluvial fan (Qa_1) deposits. Locally inset against higher, old terrace-gravel (Qg_3) deposits. Thickness, 2 to 7 m (6 to 23 ft)

Qa_2 **Intermediate alluvial fan deposits (Holocene and Pleistocene)**—Similar to young alluvial fan (Qa_1) deposits and partly cemented by calcite and gypsum. Locally overlapped by young alluvial fan (Qa_1), intermediate terrace-gravel (Qg_2), and talus (Qt) deposits. Locally include abundant subrounded to subangular basalt clasts. Support moderate growths of sagebrush, cactus, and grass. Thickness, 2 to 5 m (6 to 15 ft)

Qg_3 **Old terrace-gravel deposits (Pleistocene)**—Similar to young and intermediate terrace-gravel (Qg_1, Qg_2) deposits, but 2 to 4 m (6 to 12 ft) higher than intermediate terrace-gravel (Qg_2) deposits and 4 to 8 m (12 to 25 ft) above local drainages. Composed of well-rounded limestone, sandstone, chert, and basalt clasts in sandy gravel matrix. Basalt clasts mainly derived from the Diamond Butte and Twin Butte area but may contain clasts from areas such as Poverty Knoll south and southwest of the map area. Partly consolidated by calcite, clay, and gypsum cement. Thickness, 6 m (18 ft)

Qa_3 **Old alluvial fan deposits (Pleistocene)**—Similar to young and intermediate alluvial fan (Qa_1, Qa_2) deposits, but 2 to 3 m (6 to 10 ft) higher than intermediate alluvial fan (Qa_2) deposits and about 30 m (100 ft) above local drainages. Intertongue with talus (Qt) and old terrace-gravel (Qg_3) deposits. Often adjacent to or overlapped by young and intermediate alluvial fan (Qa_1, Qa_2) and talus (Qt) deposits. Include abundant basalt clasts near Diamond Butte and Twin Butte. Locally include abundant rounded basalt clasts (southwest quarter of quadrangle) derived from Poverty Knoll about 10 km (6 mi) southwest of map area. Thickness, 1 to 9 m (3 to 30 ft)

VOLCANIC ROCKS

Qmb **Basalt of Moriah Knoll (Pleistocene)**—Informally named for Moriah Knoll, secs. 12 and 13, T. 37 N., Rs. 8 and 9 W. (Moriah Knoll, U.S. Geological Survey 7.5' quadrangle), about 1.5 km (1 mi) east of the east-central edge of map area, northern Mohave County, Arizona. Black, aphanitic, vesicular alkali-olivine basalt. Contains scattered red and green olivine crystals. Vesicles commonly filled with calcite. K-Ar age is 2.3±1.5 and 1.5±1.5 Ma, although these ages are not reliable (Harold Mehnert, U.S. Geological Survey, written commun., 1993). Assumed age is about 850 ka. Thickness, 3 m (10 ft)

Little Tanks Basalt (Pleistocene)—Named for Little Tanks reservoir (sec. 5, T. 36 N., R. 10 W.), northern Mohave County, Arizona, south-central part of map area (Little Tanks, U.S. Geological Survey 7.5' quadrangle). Includes basalt flows, associated dikes, and pyroclastic deposits. See text for discussion

Qli **Intrusive dike or vent area**—Dark-gray, finely crystalline, aphanitic alkali-olivine basalt. Contains black augite and red and green olivine crystals. Sources for basalt flows are at pyroclastic cone deposits north and south of local drainage southeast of Little Tanks reservoir

Qlp **Pyroclastic deposits**—Red-brown and black fragments of angular basaltic scoria and cinders. Include dark-gray augite and olivine glass fragments; unconsolidated. Associated with vent and dike extrusions. Form pyroclastic cone as much as 40 m (130 ft) thick

Qlb **Basalt flows**—Dark-gray, finely crystalline, aphanitic groundmass composed of plagioclase, olivine, and augite (Fitton, 1989). Include two areas of basalt flows that radiate out from dikes or pyroclastic vent area. Surfaces partly covered by cinder and pyroclastic (Qlp) deposits. K-Ar age is 1.0±0.4 Ma (Harold Mehnert, U.S. Geological Survey, written commun., 1993). Overlie Harrisburg Member of the Kaibab Formation, lower red member and Virgin Limestone Member of the Moenkopi Formation, and old alluvial fan (Qa_3) deposits. Approximately 6 m thick

Tdb **Basalt of Diamond Butte (Pliocene)**—Informally named for Diamond Butte, sec. 33, T. 37 N., R. 10 W. (Russell Spring, U. S. Geological Survey 7.5' quadrangle), south-central part of map area, northern Mohave County, Arizona. Includes basalt flows on Twin Butte about 4 km (2.5 mi) east of Diamond Butte. Dark-gray, massive, finely crystalline, aphanitic groundmass; includes sparse red and green olivine phenocrysts. Forms caprock on Diamond Butte and Twin Butte. Source unknown, assumed to have originated from local feeder dikes near Diamond Butte now covered by landslide (Ql) deposits. K-Ar age is 4.3±0.6 Ma (Harold Mehnert, U.S. Geological Survey, written commun., 1993). Consists of one, possibly two flows. Thickness, 30 m (100 ft)

SEDIMENTARY ROCKS

Moenkopi Formation (Middle? and Lower Triassic)—Includes, in descending stratigraphic order, upper red member, Shnabkaib Member, middle red member, Virgin Limestone Member, lower red member, and Timpoweap Member, as used by Stewart and others (1972). Boundary between Middle and Lower Triassic is in upper part of upper red member (Morales, 1987)

Ŧmu **Upper red member (Middle? and Lower Triassic)**—Heterogeneous interbedded slope- and ledge-forming sequence of red sandstone, siltstone, mudstone, conglomerate, and minor gray gypsum. Includes cliff of thin-bedded sandstone in upper part. Top of unit is eroded and unconformably overlain by the basalt of Diamond Butte at Diamond Butte and Twin Butte; most complete section is at Twin Butte. Gradational contact with underlying Shnabkaib Member placed arbitrarily at top of highest, thick, white siltstone and dolomite bed of the Shnabkaib Member. Thickness, 105 m (345 ft)

Ћms **Shnabkaib Member (Lower Triassic)**—Interbedded, white, laminated, slope- and ledge-forming, aphanitic interbedded dolomite, calcareous sandstone, and silty gypsum; includes red, thin-bedded mudstone, siltstone, and sandstone beds in lower part. Gradational contact with underlying middle red member arbitrarily placed at base of lowest bed of light-gray dolomitic limestone or siltstone of the Shnabkaib Member. Thickness, 100 m (300 ft)

Ћmm **Middle red member (Lower Triassic)**—Interbedded, red-brown, slope-forming, thin-bedded, laminated siltstone and sandstone, white and gray gypsum, minor white platy dolomite, green siltstone, and gray-green gypsiferous mudstone. Gradational contact with underlying Virgin Limestone Member placed at top of highest gray limestone bed of the Virgin Limestone Member. Thickness, 80 m (260 ft)

Ћmv **Virgin Limestone Member (Lower Triassic)**—Consists of two and sometimes three light-gray, ledge-forming limestone beds 1 to 2 m (3 to 6 ft) thick separated by white, pale-yellow, and gray slope-forming, thin-bedded, gypsiferous siltstone. Includes brown, red, and green thin-bedded siltstone, gray limestone, and brown platy calcarenite. Lowest limestone bed contains star-shaped crinoid plates and poorly preserved *Composita* brachiopods in top part. Unconformable lower contact with underlying lower red member; erosional relief as much as 1 m (3 ft) truncates underlying red siltstone of lower red member at base of lowest gray bed of Virgin Limestone Member, which thickens and thins laterally as channel-fill deposit. Thickness, 25 to 30 m (80 to 100 ft)

Ћml **Lower red member (Lower Triassic)**—Interbedded, red, slope-forming, fine-grained, thin-bedded, gypsiferous sandy siltstone, gray, white, and pale-yellow laminated gypsum and minor sandstone. Lower beds contain reworked gypsum and siltstone of the Harrisburg Member of the Kaibab Formation. Interbedded or gradational contact with sandstone or conglomerate beds of underlying Timpoweap Member arbitrarily placed at lowermost red siltstone bed in Triassic paleovalleys eroded into underlying Harrisburg Member of the Kaibab Formation. Commonly forms unconformable contact with underlying Harrisburg Member of the Kaibab Formation where unit is not in contact with the Timpoweap Member. Locally thickens and thins laterally as stream-channel deposit in lower part in Triassic paleovalleys. Thickness, 3 to 25 m (10 to 80 ft)

Ћmt **Timpoweap Member (Lower Triassic)**—Light-gray, cliff-forming conglomerate and sandstone. Conglomerate composed of subangular to rounded pebbles and cobbles of gray and dark-gray limestone, white and brown chert, and rounded quartzite in matrix of gray to brown, coarse-grained, low-angle, crossbedded, calcareous sandstone, gravel, and minor siltstone. Lithologic material is locally derived from the Kaibab Formation. Occupies Triassic paleovalleys eroded into underlying members of the Kaibab Formation estimated as much as 70 m (230 ft) in depth and about 1,800 m (5,900 ft) wide. Rocks of the Timpoweap Member occupy several paleovalleys. Paleovalleys and tributary paleovalleys are scattered throughout map area (Ћmt). Imbrication of basal pebbles in conglomerate show an eastward paleoflow of depositing streams. Thickness, 6 to 80 m (20 to 65 ft)

Ћmlt **Lower red member and Timpoweap Member, undivided (Lower Triassic)**—Same lithologies as lower red member (Ꞧml) and Timpoweap Member (Ꞧmt) of the Moenkopi Formation. Composed of interbedded conglomerate lenses and limestone beds within interbedded slope and ledge sequence of reddish siltstone and gypsum beds. Occupies and fills shallow Triassic paleovalleys with relief as much as 20 m (65 ft) eroded into underlying Harrisburg Member of Kaibab Formation. Unconformable contact with Harrisburg Member of the Kaibab Formation. Unit is locally obscure where overlain by surficial deposits. Thickness, 5 to 20 m (15 to 65 ft)

Kaibab Formation (Lower Permian)—Includes, in descending stratigraphic order, Harrisburg and Fossil Mountain Members as defined by Sorauf and Billingsley (1991)

Pkh **Harrisburg Member**—Includes an upper, middle, and lower part not mapped separately. Upper part consists mainly of slope-forming, red and gray, interbedded gypsiferous siltstone, sandstone, gypsum, and thin-bedded gray limestone. Includes a resistant pale-yellow or light-gray, fossiliferous (mollusks and algae), sandy limestone bed at top of unit averaging about 1 m (3 ft) thick. Most of upper part is eroded from map area except in northwest and southwest corners. Forms gradational contact with underlying middle part. Middle part is composed mainly of two cliff-forming marker limestone beds: upper bed is gray, thin-bedded, cherty limestone, which weathers dark brown or black and often forms bedrock surface of map area, and lower bed is light-gray, thin-bedded, sandy limestone. A minor erosional unconformity separates middle part from underlying lower part. Lower part consists of slope-forming, light-gray, fine- to medium-grained, gypsiferous siltstone, sandstone, medium-grained, thin-bedded gray limestone, and gray, massive bedded gypsum. Dissolution of gypsum in lower part has locally distorted both limestone beds of middle part causing them to slump or bend into local surface drainage areas. Gradational and arbitrary contact between siltstone slope of the Harrisburg Member and limestone cliff of the Fossil Mountain Member. Harrisburg Member, in general, forms slope with a middle limestone cliff. Thickness, 100 m (300 ft)

Pkf **Fossil Mountain Member**—Light-gray, cliff-forming, fine- to medium-grained, thin-bedded, fossiliferous, sandy, cherty limestone. Chert weathers black. Contact with underlying Woods Ranch Member of the Toroweap Formation is marked at base of limestone cliff. Dissolution of gypsum and channel erosion form the unconformity between the Fossil Mountain Member of the Kaibab Formation and underlying Woods Ranch Member of the Toroweap Formation with relief as much as 5 m (18 ft), but locally as much as 75 m (250 ft); unconformity locally obscured by talus and or minor landslides (Qt) deposits. Thickness, 110 m (360 ft)

Toroweap Formation (Lower Permian)—Includes, in descending stratigraphic order, Woods Ranch, Brady Canyon, and Seligman Members as defined by Sorauf and Billingsley (1991)

Ptw **Woods Ranch Member**—Gray, slope-forming gypsiferous siltstone and pale-red silty sandstone interbedded with medium-bedded white laminated gypsum. Beds are locally distorted due to local gypsum dissolution. Forms gradational and arbitrary contact with underlying cliff-forming Brady Canyon Member of the Toroweap Formation. Thickness, 12 to 75 m (40 to 250 ft)

Ptb **Brady Canyon Member**—Gray, cliff-forming, fetid, medium-bedded, fine- to coarse-grained fossiliferous limestone; weathers dark gray. Includes thin-bedded dolomite in upper and lower part. Limestone beds average about 0.5 m (2 ft) thick. Includes chert lenses and nodules in limestone beds but these are 50 percent less than in the Fossil Mountain Member of the Kaibab Formation. Forms gradational and arbitrary contact with underlying Seligman Member of the Toroweap Formation; contact commonly covered by minor landslide (Ql) or talus (Qt) deposits. Thickness, 75 to 90 m (250 to 300 ft)

Pts **Seligman Member**—Composed of an upper, gray, slope-forming, interbedded, thin-bedded dolomite and gypsiferous sandstone; middle, gray to red, slope-forming, thin-bedded, interbedded siltstone, sandstone, and gray gypsum; and a lower, brown, purple, and yellow, cliff- or ledge-forming, fine- to medium-grained, thin-bedded, low- to high-angle crossbedded and planar-bedded sandstone. Lensing crossbedded sandstone bed is the northern extension of the Coconino Sandstone that forms a mappable cliff unit in Grand Canyon (Billingsley and others, 2000; 2001). Forms unconformable, sharp planar contact with underlying sandstone of the Hermit Formation having local relief as much as 1 m (3 ft). Thickness, 50 to 60 m (165 to 200 ft)

Ph **Hermit Formation (Lower Permian)**—Light-red, yellowish-white, ledge- and slope-forming, fine-grained, thin- to medium-bedded sandstone and siltstone. Includes yellowish-white, ledge-forming sandstone beds separated by red, slope-forming siltstone and silty sandstone beds in upper part. Upper reddish sandstone beds commonly contain yellow bleached spots, locally all beds have been bleached yellowish white by groundwater dissolution. Upper sandstone beds gradually thicken or change facies north toward Utah to become white massive marine sandstone; beds thin south and change facies to become red thin-bedded fluvial sandstone and siltstone beds in western Grand Canyon. Middle part is mostly covered by talus and alluvial deposits but is composed of red, thin-bedded sandstone and siltstone. Lower part is covered by alluvial deposits in the map area; unit is incomplete. Thickness, 75 m (250 ft), total thickness at nearest complete outcrop in Grand Canyon, 214 m (700 ft)

Pe **Esplanade Sandstone (Lower Permian)**—Upper part is red, ledge- and slope-forming, fine-grained, thin-bedded siltstone and light-red sandstone. Middle part is light-red and tan, cliff-forming, fine- to medium-grained, medium- to thick-bedded, low- and high-angle crossbedded sandstone and dolomitic sandstone. Lower part is dark-red, slope-forming, thin-bedded siltstone and sandstone. Includes thin-bedded sandy dolomitic limestone tongues of the Pakoon Limestone in middle cliff that thicken west and pinch out east (McKee, 1982). Thickness, 138 m (450 ft). Unit not exposed in the map area but assumed to be present in the subsurface based on exposures in the Grand Canyon about 30 km (20 mi) south of the map area (Huntoon and others, 1981; Wenrich and others, 1996)

IPw **Wescogame Formation (Upper Pennsylvanian)**—Light-red and reddish-gray, ledge- and slope-forming, medium- to coarse-grained, medium-bedded dolomitic sandstone and red, fine-grained, thin-bedded, cross-stratified sandstone. Thickness, 60 m (200 ft). Unit not exposed in map area but assumed to be present in the subsurface based on exposures in the Grand Canyon about 30 km (20 mi) south of the map area (Huntoon and others, 1981; Wenrich and others, 1996)

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APPENDIX

DIGITAL DATABASE DESCRIPTION FOR THE GEOLOGIC MAP OF THE UPPER HURRICANE WASH AND VICINITY, MOHAVE COUNTY, NORTHWESTERN ARIZONA

By Helen C. Dyer and Debra L. Block

INTRODUCTION

This appendix serves to introduce and describe the digital files that are included in this publication, available for downloading at *http://geopubs.wr.usgs.gov*. These files include a set of ARC/INFO geospatial databases containing the geologic information as well as Adobe Portable Document Format (PDF) and Postscript plot files containing images of the geologic map sheet and the text of an accompanying pamphlet that describes the geology of the area.

The digital map publication, compiled from previously published and unpublished data and new mapping by the author, represents the general distribution of surficial and bedrock geology in Upper Hurricane Wash and vicinity. Together with the accompanying geologic description pamphlet, it presents current knowledge of the geologic structure and stratigraphy of the area covered. The database identifies map units that are classified by age and lithology following the stratigraphic nomenclature of the U.S. Geological Survey. The scale of the source maps limits the spatial resolution (scale) of the database to 1:31,680 or smaller. The content and character of the database, as well as three methods of obtaining the database, are described below.

FOR THOSE WHO DON'T USE DIGITAL GEOLOGIC MAP DATABASES

Two sets of plot files containing images of much of the information in the database are available to those who do not use an ARC/INFO compatible Geographic Information System (GIS). There is a set available in PostScript format and another in Acrobat PDF format (see sections below). Those who have computer capability can access the plot file packages in either of the two ways described below (see the section "Obtaining the digital data"); however, these packages do require gzip or WinZip utilities to access the plot files. Those without computer capability can obtain plots of the map files through U. S. Geological Survey Information Services.
Be sure to request map MF-2410.
U. S. Geological Survey Information Services
Box 25286
Denver, CO 80225-0046
1-888-ASK-USGS
e-mail: ask@usgs.gov

DATABASE CONTENTS

This report consists of three digital packages. The first is the PostScript Plotfile Package, which consists of PostScript plot files of the geologic map and map explanation. The second is the PDF Plotfile Package which contains the same plotfiles as the first package as well as the geologic description, but in Portable Document Format (PDF). The third is the Digital Database Package which contains the geologic map database itself and the supporting data.

PostScript Plotfile Package
This package contains the PostScript images described below:

uhmap.eps	A PostScript plotfile containing the complete map composition with geology, base map, correlation chart, and crosssection of the Upper Hurricane Wash area at a scale of 1:31,680

uhmap.ai	An Adobe Illustrator plotfile containing the complete map composition with geology, base map, correlation chart, and cross-section of the Upper Hurricane Wash area at a scale of 1:31,680

The PostScript image of the geologic map and map explanation is 42 inches high by 45 inches wide, so it requires a large plotter to produce paper copies at the intended scale. The map sheet has been successfully plotted on a Hewlett Packard Designjet 5000PS printer. The PostScript plotfile of the geologic map was initially produced by the 'postscript' command with compression set to zero in ARC/INFO version 8.0. The list of map units, correlation chart, and crosssection were created in Adobe Illustrator 9.0.

PDF Plot file Package
This package contains the PDF images described below:

uhmap.pdf	A PDF file containing the complete map composition with geology, base map, correlation chart, and crosssection of the Upper Hurricane Wash area at a scale of 1:31,680
mf2410.pdf	A PDF file containing an image of the pamphlet with detailed unit descriptions and geologic information plus sources of data and references cited

The PDF image of the geologic map and map explanation was created from a PostScript file using Adobe Acrobat Distiller. The PDF image of the pamphlet was produced in Microsoft Word 2000 using the 'Convert to Adobe PDF' option from the Acrobat pulldown. In test plots we have found that paper maps created with PDF files contain almost all the detail of maps created with PostScript plot files. We would, however, recommend that those users with the capability to print the large PostScript plot files use them in preference to the PDF files.
To use PDF files, the user must get and install a copy of Adobe Acrobat Reader. This software is available free from the Adobe website (http://www.adobe.com/). Please follow the instructions given at the website to download and install this software. Once installed, the Acrobat Reader software contains an on-line manual and tutorial.

Digital Database Package
The database package is composed of geologic map database files for the Upper Hurricane Wash area. The digital maps, or coverages, and their associated INFO directories have been converted into ARC/INFO export files. These export files are uncompressed and are easily handled and compatible with some Geographic Information Systems other than ARC/INFO. Please refer to your GIS documentation.
ARC export files are converted to ARC/INFO format using the ARC command 'import'. To ease conversion and preserve naming convention, an AML is enclosed that will convert all the export files in the database to coverages and will also create an associated INFO directory. From the ARC command line type *&r import.aml.* The export files included are

ARC/INFO export file	Resultant Coverage	Description
uh_poly.e00	uh_poly/	Faults, depositional contacts, and rock unit
uh_dip.e00	uh_dip/	Strike and dip information and annotation, point data and annotation
uh_fold.e00	uh_fold/	Fold axes and basalt flow direction
uh_anno.e00	uh_anno/	Unit labels, fault names, and fault separation values

The database package also contains the following files:

import.aml	ASCII text file in ARC Macro Language to convert ARC export files to ARC coverages in ARC/INFO
mf2410.txt	A text-only file containing an unformatted version of mf2410.pdf
mf2410.met	A parseable text-only file of publication level FGDC metadata for this report
mf2410.rev	A text only file describing revisions, if any, to this publication
uhtopo_rect.tif	Rectified topographic image saved to a TIFF file
uhtopo_rect.tfw	Tansformation parameters for the topographic that are written to a world file

The following supporting directory is not included in the database package, but is produced in the process of reconverting the export files into ARC coverages.

info/	INFO directory containing files supporting the database

OBTAINING THE DIGITAL DATA

The digital data may be obtained from
the Western Region Geologic Publication Web Page at
http://geopubs/wr.usgs.gov/map-mf/mf2410/
Follow the directions to download the files.
U.S. Geological Survey Western Region FTP server. The FTP address is:
geopubs.wr.usgs.gov
The user should log in with the user name 'anonymous' and then input their e-mail address as the password. This will give the user access to all the publications available via FTP from this server. The files in this report are stored in the subdirectory: pub/map-mf/mf2410.

DATABASE SPECIFICS

Digital Compilation
Stable-base maps (scribe coat) were scanned at the U.S. Geological Survey Flagstaff field center using the Optronics 5040 raster scanner at a resolution of 50 microns (508 dpi). The resulting raster files were in RLE format, converted to the RLC format, and then to TIFF. A tic file was created in latitude/longitude coordinates and projected into the base map projection (State Plane). Each fold and dip coverage and the polygon (geology) coverage was converted to a GRID then vectorized using the command 'gridline'. All editing and attributing was done using custom pull-down and form menus.

Map Projection

Parameter	Description
Projection	STATEPLANE
Units	Meters on the ground
Zone	3201
Datum	NAD27

Database Fields
The content of the geologic database can be described in terms of the lines, points and areas that compose the map.

Each line, point, or area in a map layer or index map database (coverage) is associated with a database entry stored in a feature attribute table. Each database entry contains both a number of items generated by ARC/INFO to describe the geometry of the feature and one or more items defined by the author to describe the geologic information associated with that entry. Each item is defined as to the amount and type of information that can be recorded. Descriptions of the database items use the terms explained below.

Parameter	Description
Item Name	Name of database field
Width	Maximum number of characters or digits stored
Output	Output width
Type	B - binary integer; F- binary floating point number, I - ASCII integer, C - ASCII character string
N.Dec	Number of decimal places maintained for floating point numbers

LINES

The arcs are recorded as strings of vectors and described in the arc attribute table (AAT). The geologic identities of the boundaries are stored in the LTYPE field. They represent the contacts and faults that define the boundaries of the map units in uh_poly and linear features that do not bound map units in uh_fold.

Arc Attribute Table Definition

Item Name	Width	Output	Type	N.Dec	Description
FNODE#	4	5	B	—	Starting node of the arc
TNODE#	4	5	B	—	Ending node of the arc
LPOLY#	4	5	B	—	Polygon to the left of the arc
RPOLY#	4	5	B	—	Polygon to the right of the arc
LENGTH	8	18	F	5	Length of the arc in meters
UH_POLY#	4	5	B	—	Unique internal number
UH_POLY-ID	4	5	B	—	Unique identification number
LTYPE	35	35	C	—	Line type
PTTYPE	35	35	C	—	Point type for arc markers
PLUNGE	3	3	I	—	Coded integer to draw arrowhead (uh_fold only)

Domain of Line Types recorded in LTYPE field

uh_poly

contact_certain
fault_normal_approx
fault_normal_certain
fault_normal_concealed
landslide_scarp
map_boundary

uh_fold

anticline_approx
anticline_certain
anticline_concealed
basalt_flow_direction
monocline_certain
monocline_concealed
plunging_anticline
plunging_syncline
plunging_syncline_approx
syncline_certain
syncline_concealed

syncline_inferred
map_boundary

Domain of Markers recorded in PTTYPE field

uh_poly

fault_ball_fill
xx

uh_fold

syncline
anticline
monocline
xx

Arcs with PTTYPE value 'xx' indicate that there is no symbol attached to the arc.

POLYGONS

Map units (polygons) are described in the polygon attribute table (PAT). This identifies the map units recorded in the PTYPE field by map label. Individual map units are described more fully in the accompanying text.

Definition of Polygon Attribute Table

Item Name	Width	Output	Type	N.Dec	Description
AREA	8	18	F	5	Area of polygon in square meters
PERIMETER	8	18	F	5	Length of perimeter in meters
<COVERAGE>#	4	5	B	—	Unique internal number
<COVERAGE>-ID	4	5	B	—	Unique identification number
PTYPE	5	5	C	—	Unit label

Domain of PTYPE (map units)

Ph	Qa3	Qli	TRmm
Pkf	Qaf	Qlp	TRms
Pkh	Qf	Qmb	TRmt
Ptb	Qg1	Qs	TRmu
Pts	Qg2	Qt	TRmv
Ptw	Qg3	Qv	Tdb
Qa1	Ql	TRml	
Qa2	Qlb	TRmlt	

Plain text is substituted for conventional geologic age symbols (TR for Triassic) shown on the map.

POINTS

Point information (attitudes of planar and linear features) is recorded as coordinate data with related information. This information is described in the point attribute table (PAT). ARC/INFO coverages cannot hold both point and polygon information, thus uh_dip has only a point attribute table, and uh_poly has only a polygon attribute table.

Definition of Point Attribute Table

Item Name	Width	Output	Type	N.Dec	Description
AREA	8	18	F	5	Area (degenerative)
PERIMETER	8	18	F	5	Perimeter (degenerative)
<COVERAGE>#	4	5	B	—	Unique internal number
<COVERAGE>-ID	4	5	B	—	Unique identification number
PTTYPE	35	35	C	—	Point type

DIP	3	3	I	—	Dip angle
STRIKE	3	3	3	—	Strike angle in azimuth

Domain of Points recorded in PTTYPE field

approx_bedding
Bedding
collapse_structure
Dome
Mine
Sinkhole
vertical_joint

ANNOTATION

The coverage uh_anno contains all annotation for the polygon coverage. It is defined somewhat differently from the polygon and dip coverages. The arc attribute table is of negligible importance. Arcs in this coverage are merely leaders from a unit annotation to the related polygon. The coverage contains annotation with unit labels, fault separation, and monocline names. Annotation directly related to unit labeling is contained in subclass "anno.unit" and annotation including fault separation values and fault names is contained in subclass "anno.structure".

BASE MAP PROCEDURE

The base map was prepared by mosaicing four 1:24,000 topographic sheets and scanning to generate a georeferenced TIFF (GeoTIFF) graphic. This graphic was subsequently projected into STATEPLANE, rotated and clipped into a secondary TIFF image to be used as the topographic base map for the cartographic layout.

SPATIAL RESOLUTION

Use of this digital geologic map database should not violate the spatial resolution of the data. Although the digital form of the data removes the constraint imposed by the scale of a paper map, the detail and accuracy inherent in map scale are also present in the digital data. This database was created and edited at a scale of 1:31,680; higher resolution data is generally not present. Plotting at scales of larger than 1:31,680 will not yield greater real detail, but may reveal fine-scale irregularities below the intended resolution.